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EMERGENCY RESPIRATORY PROTECTION IN THE ATOMIC AGE*

By Julius Hannoch

Civil defense organizers, municipal fire departments, industrial emergency teams, and other individuals and groups who will be responsible for dealing with an emergency where the hazards of ionizing radiation are involved must be concerned with the problems of appropriate respiratory protection. The problems facing these persons are not particularly different from those confronting the rapidly expanding number of researchers who use radioisotopes in universities, hospitals, and industries and who have been called upon to determine appropriate respiratory protection under unusual operating conditions or in an emergency. Now, however, extensive practical experience with this type of hazard derived from operations within the atomic energy program is available. By drawing freely on this experience it is possible to postulate the basic principles from which a satisfactory program of emergency respiratory protection (where a radiation hazard is involved) can be developed.

Unfortunately, a common fallacy in the approach to many problems of radiation safety is to assume that all the appropriate protective techniques are "unique." It is not uncommon even to find consideration of respiratory protection distinctly separated into the study of (a) respiratory protective equipment designated for use where there is a radiation hazard, and (b) respiratory protective equipment designated for use where no radiation hazard is involved. Dichotomous thinking of this type is of considerably more harm than good. In many emergency situations where a radiation hazard exists, the problems concerned with other harmful atmospheric contaminants or oxygen deficiency may coexist and, conceivably, be of far greater importance. For this reason, although giving especial attention to the radiation factor, the attempt shall be made to review the conventional classes of respiratory protective equipment in such a manner that their "whole use" is made evident.

Essential to the planning of proper protective equipment for any potential emergency is an understanding of the basic hazards against which protection may be necessary and the form in which such hazards may appear. Since the nature of the radiation hazard is somewhat more "intangible" (ionizing radiation cannot ordinarily be detected by the senses) than, for example, a typical chemical hazard, it is desirable that we review briefly

*Photographs courtesy of the Mine Safety Appliances Co., Pittsburgh, Penn.

the fundamental hazard associated with ionizing radiation in order that we may clearly understand the specific role of respiratory protective equipment in affording protection against this hazard.

Whether dealing with problems created by internal or external irradiation the basic physiological phenomenon is essentially the same. Radioactive particles and rays are hazardous to the human organism because of their ability to ionize (i.e., destroy the electrical neutrality) of the atoms that make up the various elements found in the body tissues. The complex combinations of the atoms of nitrogen, carbon, oxygen, and the numerous other elements of which the cells of our bodies are composed are seriously upset by ionization and related processes. The precise mechanism by which the body is damaged as a result of these processes is, as yet, not fully known. It is known, however, that the body cells can be injured or perhaps destroyed and bodily functions can be affected in varying degrees ranging all the way from the completely undetectable (if not harmless) to completely lethal depending upon the degree and manner of the exposure, the radiomaterial involved, and the radiosensitivity of the individual and tissue exposed.

The objectives of a radiation safety program are therefore essentially twofold, namely:

1. To assure that the external irradiation is kept below a permissible exposure limit, and

2. To prevent the entrance of radiomaterials into the body by ingestion, inhalation, or through the skin.

Accomplishment of the first objective is facilitated by maintaining proper distance between the radiation source and the individual exposed, by limiting the time during which an individual is exposed to the radiation, or by interposing appropriate shielding between the exposed personnel and the sources of radiation.

While the permissible exposure limit for persons who may work with radiomaterials for the rest of their lives is generally regarded as 300 mr* per week, it is assumed that emergency personnel who may at most experience an occasional brief exposure can safely receive a much larger dose. Exposures of 1 to 5 r are often regarded as readily permissible for emergency workers. For a single "nonrepeat" exposure a subcommittee of the National Committee on Radiation Protection has recommended approval of as much as 50 r under specified conditions. It should be pointed out that a person is much more susceptible to radiation if it is delivered to the whole body

*One thousand milliroentgens equal 1 r. The roentgen unit (r) is defined as "that quantity of x or gamma radiation such that the associated corpuscular emission per 0.001293 g of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign." This indicates the absorption of 83 ergs/g of air, or slightly more per gram of tissue. Since this unit precludes the measurement of ionization by radiations other than photons, a new unit, roentgen equivalent physical (rep), has been introduced. One rep is defined as "that dose of any ionizing radiation which produces energy absorption of 93 ergs/g of tissue" or, in formulation, 1 rep equals 1 gram-roentgen per gram of tissue. Exposure limits, therefore, are more correctly specified in terms of "rep" rather than "r".

rather than a localized area or extremity except, of course, where vital organs may be concerned. A series of X-ray treatments to a surface cancer, for example, may correspond to several thousand roentgens whereas a whole-body exposure of about 500 r would prove fatal to about 50 per cent of those receiving this dose.

The second objective of a radiation safety program, to prevent the entrance of radiomaterials into the body by inhalation, ingestion, or through the skin,* is accomplished with the customary difficulties attendant upon any control measure in which elements of personal habit are involved.

The problems of ingestion are mitigated very largely by good personal hygiene measures. These include such simple practices as the abstinence of smoking or eating in any location where radiomaterials may be present, pipetting with manual devices rather than by mouth, and thoroughly washing the hands and checking them for contamination with a suitable instrument before eating or smoking after working in radiation areas.

Protection against the introduction of radiomaterials into the body through the skin is achieved by comparable measures. The role of protective clothing for such purposes is obvious. The importance of rapid first aid measures where any skin breaks or wounds, however minor, are caused by objects which might be contaminated should be recognized. Flushing such injuries immediately with large quantities of water and the prompt seeking of medical attention is considered necessary as well as evaluating the amount of radioactivity which may have entered the body through the wound.

Protection against the inhalation of radiomaterials, however, is our principal concern here. In normal operations this is accomplished to a large degree in a manner similar to the control of other harmful dusts and gases in industry. The two principal operational approaches to this problem have been the design of highly efficient (and often ingenious) ventilating systems, and the processing of materials while being kept moist insofar as possible. In the laboratory utilization of the "drybox," an airtight, glass-front glove box in which necessary manipulations can be

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*Alpha particles (positively charged helium nuclei) have tremendous ionizing power (about 10,000 times that of gamma rays) but are stopped by the surface layer of the skin. Beta particles (negatively charged electrons) have almost 100 times the ionizing power of gamma rays. Ordinarily stopped by clothing, beta particles are capable of traveling only a few yards through the air and penetrating about a fifth of an inch into the skin. Once inside the body, however, alpha and beta particles do not meet such barriers and are capable of causing serious damage. Since alpha- and beta-emitting sources lose their energy in a small distance from the source, they cause much greater local damage than gamma sources when they are located within an organ of the body. A general safety rule in regard to air contamination specifies that approved respiratory protection shall be worn in any location where the concentration of long-lived air-borne alpha emitters may be greater than $3 \times 10^{-12}\ \mu c/cc$ (about 7 disintegrations/min/m^3), or in the presence of beta- and gamma-emitting materials of comparable hazard.

performed by placing the hands in the long gloves, facilitates the handling of microcurie levels of low-energy beta or gamma emitters which are highly radiotoxic if taken into the body. For the emergency worker, however, the principal protection against the inhalation of radioactive dusts or gases is obtained by the use of respiratory protective equipment, just as protection is obtained against other toxic dusts and gases not presenting a radiation hazard. In this connection it is important to reemphasize a point made earlier. The problem of the control of radioactive dusts and gases is not essentially different, even in degree, from the problems of control of harmful dusts and gases in "nonatomic" industries, which we know how to handle effectively. Actually, one of the most difficult problems of industrial toxicology in the atomic energy program has been berylliosis. Although not radioactive the causative agent, beryllium, is one of the most subtle toxic agents yet encountered by industry. As for the hazards of inhaling uranium dusts and fumes that have not been "enriched," it is the chemical action of uranium as a kidney toxin, not radioactivity, that establishes the limiting factor for soluble uranium compounds.

The various types of respiratory protective equipment which appear to have the greatest potential value in emergencies involving ionizing radiation are drawn from three general classes, namely,

1. Self-contained breathing apparatus.
2. Canister-type gas masks with particulate (mechanical) filters.
3. Mechanical-filter respirators.

A few comments on "supplied-air" type equipment also will be included in the discussion. In examining the characteristics of each of these classes of equipment, it should be emphasized that any type of respiratory protective equipment obtained commercially should carry the appropriate approval of the Bureau of Mines so that the user may be assured of its reliability for the purpose stated by the manufacturer.

Self-contained breathing apparatus is, by far, the most important single class of respiratory protective equipment pertinent to this discussion. This type of apparatus furnishes an adequate supply of breathable oxygen (or air) which is independent of the atmosphere in which the wearer is working or traveling. The self-contained breathing apparatus provides complete respiratory protection under any conditions of oxygen deficiency* or concentration of "conventional" harmful aerosols, as well as radioactive gases or particulates. The requisite pure oxygen (or air) supply is incorporated into the apparatus. Consequently, the wearer can operate entirely independent of the

*Normal air contains 21 per cent oxygen. Respiration of air containing less than 19 per cent oxygen while strenous work is being performed, or over a long period of time, may result in headache or dizziness. A person cannot function properly if the oxygen concentration is reduced to 16 per cent. Thus, a small difference in the oxygen content of inspired air is sufficient to cause a serious loss of efficiency, and perhaps death, independent of any toxic agents which may be present.

surrounding atmospheres as long as the oxygen (or air) supply lasts. Of course, added precautions must be taken in the presence of gases (e.g., hydrocyanic acid gas) and penetrating radiations (e.g., beta particles, gamma rays, and neutrons) which irritate or penetrate the skin but, other than this, self-contained breathing apparatus can be employed with absolute safety in atmospheres where the use of equipment of the filter type would be questionable or hazardous.

As a logical concomitant of this "super-protection" feature the superiority of self-contained breathing apparatus becomes apparent. Respiratory equipment, by and large, is essentially emergency equipment. In an emergency, it is not likely that one can always assay the atmosphere to determine the adequacy of the oxygen for supporting life or the extent of contamination by harmful gases or particulates, nor is this necessary when self-contained apparatus is used.* Complete isolation from the atmosphere in respiration is assured only with the use of equipment of the self-contained type.

Since the introduction of the first successful model of self-contained breathing apparatus less than fifty years ago, continual research aimed at providing complete respiratory protection in oxygen deficient and harmfully contaminated atmospheres has resulted in a variety of reliable and versatile equipment. In large measure this accounts for the increasing application of self-contained equipment, which was designed originally as a means of protecting emergency crews against the toxic gases that result from mine fires and explosions. Although all types of self-contained equipment afford the same basic protection, operating characteristics of the three principal forms are sufficiently different to require individual treatment. The three different "species" of self-contained breathing apparatus are generally classified as:

a. Self-generating type.
b. Demand type.
c. Oxygen cylinder rebreathing type.

The self-generating type of equipment (see Fig. 1) is perhaps the most revolutionary development in the history of respiratory protection. Developed just prior to the entry of the United States into World War II, this apparatus was selected by the U. S. Navy for fire-fighting service and was employed under most severe fire and battle conditions by thousands of Navy personnel for more than four years. Today, it is standard equipment in the Navy and is receiving rapidly increasing acceptance by municipal fire departments, public and private emergency crews, and nuclear research and production facilities as well as in conventional industrial operations.

The unique feature of the self-generating equipment is the chemical canister from which oxygen is generated. This canister replaces the customary cylinder of compressed gas and associated regulating valves and other

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*Of course, where an external radiation hazard is possible, suspected, or known to exist, a survey must always be made. Compact, easily operable, instantaneous-reading portable equipment is commercially available for this purpose.

mechanical components characteristic of other forms of self-contained equipment. Potassium tetroxide, the chemical compound in the canister, provides for the evolution of oxygen upon activation by the moisture in the breath and by a subsequent chemical reaction removes the carbon dioxide. Since oxygen is supplied in response to the wearer's exhalation, an adequate supply is assured regardless of whether breathing is performed at a normal or rapid rate. These canisters, not much larger than an ordinary gas-mask canister, can be stored indefinitely until used, characteristics which should be contrasted with the maintenance, service, and "bulkiness" features inherent in high-pressure compressed-gas cylinders, an inherent part of all other self-contained equipment. Although these canisters will operate at temperatures as low as -20°F after being started, preferably they should be stored and started at temperatures above freezing to facilitate start-up which normally requires only five or six breaths through the apparatus. Canisters are conveniently disposed of after use by puncturing and placing them in a nearly full bucket of water until bubbling ceases, indicating complete exhaustion of the potassium tetroxide. The canisters can then be discarded, and the resultant caustic water poured down a drain or otherwise suitably disposed of.

The self-generating type of self-contained equipment operates at all times under slight positive pressure which precludes the possibility of leakage of contaminants into the facepiece. It is routinely equipped with a speaking diaphragm* that is readily adaptable to direct connection with a sound-powered emergency communication system (see Fig. 5). The entire apparatus weighs about 13 lb complete and affords a minimum of 3/4 hr protection under the most stringent breathing conditions. It is almost as simple to operate as a gas-mask, and the apparatus as a whole is completely unique in that there are no working parts. Thus there need be no concern over the deterioration of rubber membranes and similar working parts characteristic of other apparatus which might occur under conditions of exposure to corrosive or other contaminants.

Demand-type equipment (see Fig. 2) provides the user with oxygen (or air) contained in a compressed-gas cylinder that is generally carried on the back. "Sling-type" positions for the cylinder are available for equipment with shorter operating periods. The "heart" of the mechanism is the demand regulator which provides for reducing the incoming gas from cylinder pressure to a breathable pressure and delivers to the facepiece any quantity of oxygen (or air) "demanded" by the wearer. There is no recirculation, expired breath (including any exhaled oxygen) being released through an exhalation valve in the facepiece, thus all demand apparatus are

*All gas masks and self-contained equipment can be obtained with a speaking diaphragm which, with or without connection to a sound-powered communication system, provides a means of communication by users of the equipment that is not possible to attain with ordinary facepieces.

less efficient when compared with apparatus operating on the rebreathing principle.* A pressure gauge mounted on the regulator shows the amount of oxygen (or air) in the cylinder at all times. The approximate weight of this equipment (back type) which affords complete respiratory protection for 30 min under conditions of strenuous physical exertion is about 30 lb.

Oxygen cylinder rebreathing apparatus is the oldest class of self-contained equipment. It is rapidly losing favor to the simpler, lighter, and more economical self-generating type and the less complicated demand type. It is mentioned here only to provide complete coverage of the subject. This apparatus operates through a fairly complicated closed breathing circuit in which oxygen is supplied from a steel cylinder and "delivered" to the user in accordance with his breathing requirements. Exhaled breath is passed through a chemical which removes the carbon dioxide and allows any unused oxygen to pass back into the system.

Although not technically a form of self-contained equipment, two other forms of supplied-air equipment, hose masks and air-line respirators, might be mentioned at this point. Limitations on these two types of equipment for emergency purposes, however, are clearly evident.

Air-line respirators (see Fig. 3) consist of a mask facepiece connected to a hose of small internal diameter which, in turn, is usually hooked up to a high-pressure compressed-air system from which air for the respirator is supplied after requisite filtration and pressure reduction. Although this respirator will give protection against all types of harmful aerosols, it is designed for routine protection in atmospheres that are not immediately dangerous to life. Thus the serious limitations for this type of device as emergency equipment are immediately apparent. In fact, where the use of an air-line respirator has become routinely necessary, the personnel responsible for health control might well review the operation or process to assure themselves that appropriate revision of the procedure or process might not satisfactorily eliminate the need for respiratory protection.

Hose masks are used to furnish fresh air to personnel who must enter oxygen-deficient or harmfully contaminated atmospheres. Fresh air is taken from the "outside" and drawn or blown through a hose of comparatively large (approximately 1 in.) internal diameter attached to the mask facepiece. Serious limitations on this type of equipment arise from the necessity of keeping the hose lines unfouled, the restriction of 150 ft on the maximum length of hose, and the possibility of contamination of the "outside" air with which the facepiece is supplied, a particular concern where radioactive contamination is a factor. Use of heavy wire-reenforced hose of comparatively large internal diameter in this type of equipment is intended to allow the wearer of the hose mask to escape from a contaminated area by breathing

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*Both self-generating and oxygen cylinder rebreathing types of self-contained equipment operate on the rebreathing principle which permits exhaled oxygen to be retained in the closed system, thereby prolonging the period of time during which the same piece of equipment can be used safely.

with his own power in the event of a blower failure. So much for the self-contained and supplied-air types of equipment.

The second major type of equipment is the canister-type mask with a particulate (mechanical) filter. Commercial versions of this type of equipment (Bureau of Mines Type N) afford protection against gaseous and particulate contaminants of a stated volume and type. It offers no protection against oxygen-deficient atmospheres. The two best known varieties of this type of equipment are the commercial "All-Service" mask and the military "combat" mask.

A Universal All-Service type gas mask with a particulate filter (see Fig. 4) is approved for protection against acid gases, organic vapors, and carbon monoxide not exceeding 2 per cent by volume and ammonia not exceeding 3 per cent by volume, singly or in combination. A mechanical filter provides added protection against toxic dusts, smokes, mists, and fumes. An automatic timer is provided with the equipment primarily to gauge the protection time available against carbon monoxide which, unlike most common industrial gases, is colorless, tasteless, nonirritating, and practically odorless, and thus not detectable by the senses. This universal-type gas mask provides protection from carbon monoxide specifically for a period of 2 hr in a maximum concentration of 2 per cent. A series of chemicals in the canister provides for removal of other common industrial gases, viability of the canister under such exposures depending upon the concentration of the contaminants. Of course, since the gas-mask canister operates by means of chemical removal of the contaminants, the chemicals are used up more rapidly as the concentration of the gaseous contaminants increase, and protection for the wearer is reduced correspondingly. With the exception of carbon monoxide, most gases of industrial significance are detectable by the senses of smell or taste, and the user can usually determine thereby when the can ister requires replacement. This equipment complete weighs about 6 lb and, like self-contained equipment, can be obtained with a speaking diaphragm that is readily adaptable to direct connection with a sound-powered emergency communication system (see Fig. 5). Generally speaking, where self-contained equipment is not available, an All-Service mask with a particulate filter is probably the second best choice of emergency equipment when a problem of radioactive contamination of the atmosphere is known or suspected.

According to a very recent publication by the National Security Resources Board* a combat-type gas mask, the other mask of this canister type which we shall discuss, will filter out 99.999 per cent of the particles as small as one five-hundred thousandths of an inch in diameter. It is doubtful that any commercially available respiratory equipment of the filter type affords efficiency of this degree. Thus the ability of this equipment to filter out radioactive as well as nonradioactive particles is of a very high order. Although the combat mask is not known to be available outside government channels, some comment relative to it is probably in order in view of this reference by the National Security Resources Board.

*Medical Aspects of Atomic Weapons, U. S. Government Printing Office, 1950.

A recent article in the Chemical Corps Journal* indicates that the canister of the combat mask uses an asbestos fiber filter paper and a small volume of impregnated charcoal as a gas absorbent. Of course, the Army Chemical Corps when designing any mask must give essential consideration to gases known or suspected of having military significance, and it is, therefore, obvious that these masks should afford very excellent protection against such known war gases as chloropicrin and phosgene. On the other hand, a simple charcoal filter affords no protection against ammonia or carbon monoxide, to mention a few gaseous contaminants of industrial significance. The limited service life of the combat-mask canister in the presence of harmful gaseous contaminants, indicated by the relatively small quantity of gas absorbent which is reported as a minimum of 245 ml, in all probability can be controlled with reasonable accuracy when used under military jurisdiction, and appropriate action taken. Therefore, the protection of a timing device provided in "civilian equipment" is probably unnecessary. Similarly, the use of a facepiece in the combat mask which does not conveniently fit over civilian spectacles probably affords no inconvenience in military use, since special size spectacles for use with a gas mask can be provided by the military to those who require them. The different situations existing under conditions of possible military or civilian usage, however, should be fully realized.

A most interesting contribution by the military to the design of respiratory protective equipment is exhibited in the construction of the combat mask. The canister is assembled directly to the facepiece, either at the base in a snout position or on the cheek, which eliminates the necessity of a hose tube. The possible fatigue effects upon the user of devices so constructed, however, should not be overlooked nor the possibility of deformation of the canister under rough usage. The latter point might be of some significance particularly for the lighter canisters manufactured with an aluminum shell. The weight of the combat-mask canister with an aluminum shell is reported to be 250 g.

The third major class of respiratory protective equipment is the simple (mechanical) particulate filter respirator. This type of device (Bureau of Mines Type A mechanical-filter respirator) affords no protection against gaseous contaminants, radioactive or otherwise, and no protection against oxygen deficiency--the only purpose being the filtration of particles above a given diameter. Perhaps the most serious objection to dust respirators is the difficulty of obtaining a tight fit around the face, a situation which can result in leakage. Therefore, where the particulate hazard is unusually hazardous, the simple mechanical-filter dust respirator cannot always be fully relied upon. Efficient commercial dust respirators, as exemplified by the BM 2133 "Comfo" respirator, are approved by the U. S. Bureau of Mines under Test Schedule No. 21 (see Fig. 6.) Such units, therefore, afford quite satisfactory protection for low-level exposure to most radioactive dusts and are, of course, a particularly important form of device for protection against pneumoconiosis, producing toxic dusts as well as nuisance dusts.

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*Status of the U. S. Army Service Gas Masks, October 1947.

To summarize this brief survey of respiratory protective equipment which may be of value in the presence of ionizing radiations, the selection of equipment to be used in situations where there may be radiation hazards should be based on an analysis of all respiratory protection needs as special equipment solely for protection against radiation hazards will not normally be required.

One final word of caution is in order. No piece of safety equipment is really "safe" until the user has been indoctrinated thoroughly in its use, understands its limitations, and knows the situations in which it may be employed properly. The training of persons who may be required to use emergency respiratory protective equipment along these lines is absolutely essential if maximum benefit from the use of the equipment is to be derived, and serious damage arising from misuse of the equipment is to be avoided.

Fig. 1--Self-generating type of self-contained breathing apparatus.

Fig. 2--Demand type of self-contained breathing apparatus.

Fig. 3--Air-line respirator.

Fig. 4--Universal type gas mask.

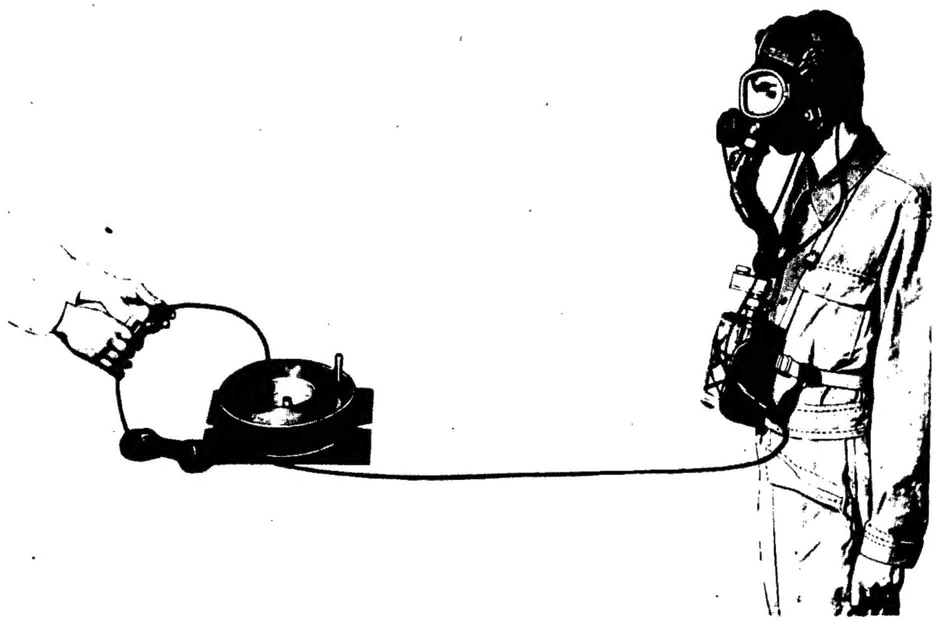

Fig. 5--Emergency sound-powered communication system connected to mask facepiece.

Fig. 6--Mechanical-filter respirator.

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